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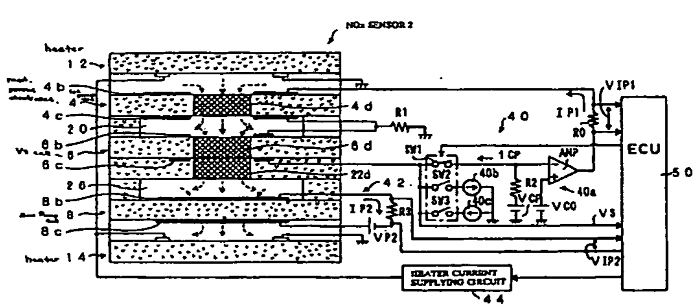
(54) **Method and apparatus for measuring oxygen concentration and nitrogen oxide concentration**

(57) Using a sole Nox sensor Nox concentration and oxygen concentration are measured accurately. A measurement device for measuring NOx concentration and oxygen concentration comprises an NOx sensor (2) having a first measurement chamber (20) communicating via a diffusion rate regulating layer (4d) with the gas under measurement and a second measurement chamber (26) communicating with the first measurement chamber (20) via diffusion rate regulating layers (6d, 22d). A first pump cell (4) and an oxygen concentration measurement Vs cell (6) are formed on the first measurement chamber (20), while a second pump cell (8) is formed on the second measurement chamber (26). Inside of the first measurement chamber (20) is controlled to a constant low oxygen concentration by controlling the first pump current (IP1) so that output of Vs cell (6) will equal a reference voltage VC0. By applying a constant voltage across the second pump cell (8) NOx in the second measurement chamber (26) is decomposed to pump out oxygen. Thus NOx concentration and oxygen concentration are measured from the second pump current (IP2) and from the first pump current (IP1), respectively. During measurement, sensor temperature is detected from the internal resistance of the Vs cell for controlling heater current supplied to heaters (12, 14) to maintain a constant sensor temperature.

FIG. 1



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detection system of the NOx concentration and oxygen concentration (air/fuel ratio) in implementing the above described NOx control.

This object is solved by the method of independent claim 1 and the device according to independent claim 4. Further advantageous aspects and details of the invention will be evident from the dependent claims, the description and the drawings. The claims are intended to be understood as a first non-limiting approach of defining the invention in general terms.

According to a first aspect of the present invention there is provided a method for measuring the oxygen concentration and the nitrogen oxide concentration in a gas under measurement using an NOx sensor having a first measurement chamber, a second measurement chamber and a heater. The first measurement chamber has preferably a first oxygen pumping cell and an oxygen concentration measuring cell and communicates with the side of the gas under measurement of a first diffusion rate regulating layer. The gas in the first or second chamber might also be called gas under measurement. The term "the side of" is intended to represent the gas under measurement, e.g. straight exhaust gas itself before entering the first chamber. The first oxygen pumping cell has advantageously an oxygen ion conductive solid electrolyte layer sandwiched between porous electrodes. The second measurement chamber has a second oxygen pumping cell preferably having an oxygen ion conductive solid electrolyte layer sandwiched between porous electrodes, and advantageously communicates with the first measurement chamber via a second diffusion rate regulating layer. The heater is adapted for heating the cells to a pre-set activation temperature. The method includes at least one of the following steps-the step of causing the current to flow in the first oxygen pumping cell so that an output voltage of the oxygen concentration measurement cell will be of a pre-set value for controlling the oxygen concentration in the first measurement chamber to a constant value, the step of applying a constant voltage across the second oxygen pumping cell in a direction of pumping out oxygen out of the first measurement chamber , and the step of measuring the concentration of the nitrogen oxide in the gas under measurement based on the value of the current flowing in the second oxygen pumping cell and measuring the oxygen concentration in the gas under measurement based on the value of the current flowing in the first oxygen pumping cell.

In a second aspect related to the first aspect, the amount of the current supplied to the heater is controlled so that the temperature of the oxygen concentration measurement cell in the NOx sensor will be a pre-set target temperature.

In a third aspect related to the second aspect, the measured results of the oxygen concentration and the nitrogen oxide concentration are corrected depending on the deviation from the target value of the temperature of the oxygen concentration measurement cell for compensating the measured results for temperature.

According to a fourth aspect of the invention there is provided a device for measuring the oxygen concentration and the nitrogen oxide concentration in a gas under measurement using NOx sensor similar to the NOx sensor stated in the first aspect. The measurement device includes pump current control means which could be a circuit or module for causing the current to flow in the first oxygen pumping cell so that an output voltage of the oxygen concentration measurement cell will be of a pre-set value for controlling the oxygen concentration in the first measurement chamber to a constant value, and advantageously constant voltage application means which could be a circuit or module for applying a constant voltage across the second oxygen pumping cell in a direction of pumping out oxygen out of the second measurement chamber. The measurement device may further comprise nitrogen oxide concentration measurement means which could be a determining circuit or module for measuring the concentration of nitrogen oxide in the gas under measurement based on the value of the current flowing in the second oxygen pumping cell, and advantageously oxygen concentration measurement means, which could be a determining circuit or module) for measuring the oxygen concentration in the gas under measurement based on the value of the current flowing in the first oxygen pumping cell.

In a fifth aspect of the present invention related to the fourth aspect, the device may further include temperature detection means which could be a determining circuit or module for detecting the temperature of the oxygen concentration measurement cell and/or heater current supplying controlling means for controlling the current supplied to the heater so that the temperature of the oxygen concentration measurement cell as detected by the temperature detection means will be a pre-set target temperature.

In a sixth aspect of the present invention related to the fifth aspect, the device may further include correction means which could be a circuit or module for temperature-compensating results of measurement of the oxygen concentration and the nitrogen oxide concentration by correcting the results of the measurement responsive to deviation from the target temperature of the temperature of the oxygen concentration measurement cell as detected by the temperature detection means.

In a seventh aspect of the present invention related to the fifth or sixth aspect, the temperature detection means advantageously detects the temperature of the oxygen concentration measurement cell by detecting the internal resistance of the measurement cell and wherein especially the heater current supply controlling means controls the amount of the current supplied to the heater so that the detected internal resistance of the oxygen concentration measurement cell will be of a preset value corresponding to the target temperature.

That is, for grasping the deterioration of the NOx catalyst, it is only necessary to detect to which extent leakage of NOx steadily occurs. To this end, it suffices to compare the control air/fuel ratio and the amount of leakage of NOx for the control air/fuel ratio in order to judge whether or not the amount of leakage of NOx relative to the control air/fuel ratio is within a pre-set allowable range.

That is, an internal combustion engine, in general, the smaller the air/fuel ratio of the supplied fuel mixture, the smaller is the amount of leakage of NOx and, conversely, the larger the air / fuel ratio, the larger the amount of leakage of NOx. Therefore, an allowable value of the amount of leakage of NOx relative to the air/fuel ratio is pre-set. Then oxygen concentration and NOx concentration are measured simultaneously during the operation of the internal combustion engine, the allowable value of the amount of leakage of NOx corresponding to the measured oxygen concentration, in other words, the air/fuel ratio, is read out, and the measured value of the NOx concentration is checked as to whether or not it is lower than the allowable value and the NOx catalyst is judged to be deteriorated if the measured value of the NOx concentration is in excess of the allowable value.

If, upon making judgment on deterioration of the NOx catalyst, different sensors are used for measuring the oxygen concentration and the NOx concentration, it may be envisaged that an error is caused in detection characteristics of the NOx concentration relative to the air/fuel ratio due to, for example, variation in characteristics from sensor to sensor or difference in the degree of deterioration, thus lowering the decision precision in deterioration of the NOx catalyst.

However, even if the individual NOx sensors undergo variation in characteristics, there is no difference in variation of detection accuracy of the NOx and the are/fuel ratio by a sole NOx sensor. Since the oxygen concentration and the NOx concentration in the gas under measurement are measured using the sole NOx sensor according to the present invention, there is no risk of an error being produced in detection characteristics of the NOx concentration relative to the air/fuel ratio, such that deterioration of the NOx catalyst can be judged at high accuracy from (based on) the measured results.

With the measurement method including the details of the second aspect, the current supplied to the heater provided in the NOx sensor is controlled so that the temperature of the oxygen concentration measurement cell in the NOx sensor will be a pre-set target temperature.

The reason is that, unless the oxygen concentration in the first measurement chamber can be controlled to be constant by current supply control to the first oxygen pumping cell (pump current control), the oxygen concentration cannot be measured correctly, such that, for controlling the oxygen concentration in the first measurement chamber to be constant, it is necessary to hold a constant temperature in the oxygen concentration measurement cell designed to measure the oxygen concentration.

Briefly, the oxygen concentration measurement cell measures the oxygen concentration in the first measurement chamber by setting porous electrode side of the oxygen concentration measurement chamber opposite to the first measurement chamber as a reference oxygen concentration (oxygen partial pressure P1), exploiting the fact that, if a solid electrolyte layer is sandwiched between a pair of porous electrodes, an electromotive force EMF given by the Nernst' equation (1):

$$EMF = A \times T \times \log(P1/P2) \qquad (1)$$

where A is a constant, and T is absolute temperature. is generated across the electrodes depending on the oxygen partial pressures P1, P2 of the electrode sides. Therefore, if, with the oxygen concentration measurement cell being at a temperature T of 1000°K and the oxygen concentration in the first measurement chamber being at 1000 ppm, the electromotive force EMF in the oxygen concentration measurement cell is 200 mV, the electromotive force EMF is 160 mV for a temperature T of 800°K. Thins, for controlling the oxygen concentration in the first measurement chamber to be constant, in other words, for correctly measuring the oxygen concentration and the NOx concentration, the temperature in the oxygen concentration measurement cell needs to be kept constant.

In particular, in the above-mentioned universal-range air/fuel ratio sensor hitherto used for measuring the oxygen concentration, the inside of the measurement chamber is controlled by the pump current control so as to be substantially (almost) depleted of oxygen (the sate of zero oxygen concentration), it is possible to obtain rather stable temperature characteristics. However, with the NOx sensor, if the inside of the measurement chamber is controlled by the pump current control so as to be substantially depleted of oxygen (the state of zero oxygen concentration), the NOx component in the gas under measurement flowing into the first measurement chamber is decomposed offering a high risk that the NOx concentration (in the gas under measurement) cannot be measured. Therefore, control is made so that a minor amount of oxygen (corresponding to, for example, a low oxygen concentration of 1000 ppm) is left in the first measurement chamber. The result is that the temperature characteristics are significantly lowered as compared to the universal-range air/fuel ratio sensor.

Fig. 10 shows the relation between the out pirnt voltage Vs of an oxygen concentration measurement cell and the pump current Ip flowing in an oxygen pumping cell in a case where the oxygen concentration of the gas under measurement is measured by pump current control employing the conventional universal-range air/fuel ratio sensor, with the oxygen concentration being fixed. As may be seen from this figure, if the pump current Ip

aspect 6 is a device for implementing the measurement method stated in aspect 3 and can compensate the measured results of the oxygen concentration and the NOx concentration for temperature, even if the oxygen concentration measurement cell temperature has been changed from the target temperature under the effect of the temperature changes of the gas under measurement despite that the oxygen concentration measurement cell temperature is controlled to the target temperature. This enables more accurate measurement of the oxygen concentration and the NOx concentration.

Although the detection means for detecting the temperature of the oxygen concentration measurement cell may be implemented by a temperature sensor device provided in the vicinity of the oxygen concentration measurement cell, the NOx sensor becomes complex in the structure in such case, also offering a difficulty in precisely detecting the temperature of the oxygen concentration measurement cell.

It is noted that the internal resistance of the oxygen concentration measurement cell is varied depending on the cell temperature, such that the internal resistance becomes lower the higher the cell temperature. Therefore, if the internal resistance of the oxygen concentration measurement cell is detected as defined in aspect 7, it becomes possible to detect the cell temperature accurately without necessity of providing a separate temperature sensor device in the NOx sensor, thus enabling simpler and more accurate temperature control.

On the other hand, in case where the internal resistance of the oxygen concentration measurement cell is detected by temperature sensor means, it suffices if a constant voltage is applied across the oxygen concentration measurement cell for sensing the internal resistance for detecting the amount of the current then flowing in the cell, or if a constant current is caused to flow in the oxygen concentration measurement cell for sensing the voltage across both electrodes (or terminals) of the oxygen concentration measurement cell.

For detecting the internal resistance of the oxygen concentration measurement cell, it is necessary to break the connection between the pump current control means and the oxygen concentration measurement cell transiently for stopping the control of current supply to the first oxygen pumping cell by the pump current control means. That is, if the current is supplied to the oxygen concentration measurement cell for detecting the internal resistance, the voltage across both electrodes of the cell ceases to correspond to the oxygen concentration in the first measurement concentration, such that, if the control operation of the pump current control means be continued at this time, the oxygen concentration in the first measurement chamber would be controlled incorrectly.

It is therefore desirable to stop the control operation by the pump current control means for precluding such mistaken control operation during measurement of the internal resistance of the oxygen concentration measurement cell.

The oxygen concentration measurement cell measures the oxygen concentration in the first measurement chamber by the electromotive force EMF obtained by equation (1). The oxygen concentration towards one of the paired porous electrodes of the cell which does not contact with the first measurement chamber needs to be a pre-set reference oxygen concentration.

To this end, a reference gas with a constant oxygen concentration, such as atmospheric air, may be introduced towards such electrode. However, for introducing the reference gas from outside, it is suitable to provide a gap or conduit for introducing the reference gas in the NOx sensor, thus complicating the NOx sensor structure.

For setting a reference oxygen concentration at a porous electrode on the side of the oxygen concentration measurement cell opposing to the first measurement chamber, it suffices if, in the NOx sensor, the porous electrode on the side of the oxygen concentration measurement cell opposing to the first measurement chamber is closed and part of oxygen in the resulting closed space can be leaked out via a leakage resistance, with the pump current control means causing a small amount of current to flow in the oxygen concentration measurement cell in a direction of pumping out oxygen in the first measurement space into the closed space to control the amount of current flowing in the first oxygen pumping cell so that, as the closed space is caused to function as an internal oxygen reference source, an electromotive force generated across the oxygen concentration measurement cell will be of a constant value, according to aspect 8. In this case, there is no necessity of providing a spacing in the NOx sensor for introducing the reference gas, thus simplifying the structure of the NOx sensor.

For measuring the internal resistance of the oxygen concentration measurement cell by temperature detection means, the temperature detection means periodically interrupts connection between the pump current control means and the oxygen concentration measurement cell so that, during such interruption, an amount of current for detecting the internal resistance larger than the small (or minute) current is caused to flow in the oxygen concentration measurement cell in an opposite direction to the flowing direction of the small current, the internal resistance of the oxygen concentration measurement cell being detected from a voltage generated at this time across the electrodes of the oxygen concentration measurement cell, according to aspect 8.

That is, since the oxygen concentration measurement cell according to the present aspect self-generates the internal oxygen reference source for itself by a small amount of current supplied thereto, a sufficient amount of oxygen is stored in the closed space operating as an internal oxygen reference source, so that, if the internal resistance detection current is caused to flow in the same direction as the small current (for the

cell sandwiched between the solid electrolyte layers provided with the first and second oxygen pumping cells, and heater substrates are arranged on bath sides thereof in the laminating direction, so that, if the amount of the current flowing in the heater is controlled for controlling the temperature of the oxygen concentration measurement cell, the first and second oxygen pumping cells can be controlled more reliably to close to the target temperatues, while the measured gas flowing from the first diffusion layer into the first measurement chamber can be sufficiently heated by the heater.

The result is that, in the measurement device stated in aspect 10, temperature variations in the respective cells of the NOx sensor can be decreased, while the respective cells are scarcely susceptible to the temperature influence of the gases under measurement, thus further increasing measurement accuracy of the oxygen concentration and the NOx concentration.

According to aspect 11, the second diffusion rate regulating layer over laps at least a portion of the first diffusion rate regulating layer in a view where the NOx sensor is projected from the laminating direction of solid electrolyte layers, and the oxygen concentration measurement cell is provided in the vicinity of the second diffusion rate regulating layer. The temperature of the NOx sensor and the gases under measurement in the sensor can be controlled more reliably to close to the target temperature, thins improving the oxygen concentration and the NOx concentration.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a schematic view showing the structure of an overall measurement device for measuring oxygen concentration and the nitrogen oxide concentration according to an embodiment of the present invention.

Fig.2 is an exploded perspective view showing the structure of the NOx sensor according to an embodiment of the present invention.

Fig.3 is a flowchart illustrating processing far measuring oxygen concentration and NOx concentration repeatedly executed by an ECU according to an embodiment of the present invention.

Fig.4 is a flowchart illustrating an internal resistance detection processing executed as interrupt processing every pre-set time period in the ECU according to the embodiment of the present invention.

Fig.5 is a chart showing the relation between the device temperature and the internal resistance of an oxygen concentration measurement cell.

Fig.6 is a chart showing the relation between the oxygen concentration of the gas under measurement free of NOx and the first and second pump currents.

Fig.7 is a timing chart showing changes in the first and second pump currents caused by changes in the exhaust gas temperature during acceleration and deceleration of an internal combustion engine.

Fig.8 is a chart showing an example of a map used for determining the amount of temperature correction for the second pump current.

Fig.9 is a timing chart illustrating the operation during internal resistance detection processing shown in Fig.4.

Fig.10 is a graph illustrating temperature characteristics of oxygen concentration obtained by pump current control in an universal range air/fuel ratio sensor

Referring to the drawings, a preferred embodiment of the present invention will be explained in detail.

Fig.1 shows a schematic structure of the entire device for measuring the oxygen concentration and the NOx concentration of the embodiment of the present invention, while Fig.2 is an exploded perspective view of an NOx sensor 2 employable for this measurement device.

The measurement device of the present embodiment shown in Fig.1 includes an NOx sensor 2 and a driving circuit 40 for switching current supply and a current supply path for a first oxygen pumping cell (sometimes referred to herein as "first pumping cell") 4 and an oxygen concentration measurement cell (sometime referred to herein as "Vs cell") 6 constituting the NOx sensor 2 and for detecting a current flowing in the first oxygen pumping cell 4 (sometimes referred to herein as "first pump current") IP1. The measurement device also includes a detection circuit 42 for applying a constant voltage across a second oxygen pumping cell (sometimes referred to herein as "second pump cell") 8 for detecting a current flowing at this time (sometimes referred to herein as the "second pump current") IP2. The measurement device also includes a heater current supplying circuit 44 for supplying a current to a pair of heaters 12, 14 provided in the NOx sensor 2 for heating the cells 4, 6 and 8, and an electronic control circuit 50, sometimes referred to herein as ECU, made up of a micro-computer, for controlling the driving circuit 40 and the heater current supplying current 44 for computing the oxygen concentration and the NOx concentration in the gas under measurement based on detection signals VIP1 and VIP2 from the driving circuit 40 and the detection circuit 42.

Referring to Fig.2, the first pump cell 4 of the NOx sensor 2 includes a plate-shaped solid electrolyte layer 4a, on both sides of which are formed rectangular porous electrodes 4b, 4c and leads 4b1, 4c1. The solid electrolyte layer 4a is passed through at a mid portion thereof by a circular hole so that the circular hole passes through the center portions of the porous electrodes 4b, 4c. The circular hole is filled (or padded) with a porous filler to form a diffusion rate regulating layer 4d.

The Vs cell 6 is provided with circular porous electrodes 6b, 6e and lead portions 6b1, 6c1 on both sides of the solid electrolyte layer 6a of the same shape as the solid electrolyte layer 4a of the first pump cell 4. The solid electrolyte layer 6a is passed through at a mid portion thereof by a circular hole so that the circular hole passes through the center portions of the porous elec-

erence voltage VC0 while having an output terminal connected via a resistor R0 to the porous electrode 4b of the first pump cell 4.

When the switch SW1 is ON, the controller 40a operates as follows:

First, a constant small (minute) current iCP is caused to flow via resistor R2 in the Vs cell 6 for pumping oxygen in the first measurement chamber 20 towards the porous electrode 6c of the Vs cell 6. Since the porous electrode 6c is closed by the solid electrolyte layer 22, while communicating with the porous electrode 6b via leakage resistance 6f, the closed space in the porous electrode 6c is of a constant oxygen concentration by the supply of the minute current iCP, thus operating as an internal reference oxygen source.

If the side of the porous electrode 6c of the Vs cell 6 operates in this manner as an internal reference oxygen source, an electromotive force is generated in the Vs cell 6 in an amount proportionate to the ratio of the oxygen concentration in the first measurement chamber 20 to that of the inner oxygen reference source, with the voltage Vs of the porous electrode 6c becoming a voltage corresponding to the oxygen concentration in the first measurement chamber 20. Since this voltage is supplied to the differential amplifier AMP, the latter outputs a voltage corresponding to the difference between the reference voltage VC0 and the input voltage (VC0 - input voltage). This output voltage is impressed to the porous electrode 4b of the first pump cell 4 via resistor R0.

The result is that the first pump current IP1 flows through the first pump cell 4. This first pump current IP1 controls the electromotive force generated in the Vs cell 6 to be a constant voltage, that is controls the oxygen concentration in the first measurement chamber 20 to be a constant concentration. Namely, the controller 40a acts as a pump current control means to control the oxygen concentration in the first measurement chamber 20 so as to bring that in the first measurement chamber constant when the gas under measurement flows into the first measurement chamber 20 via the diffusion rate regulating layer 4d.

Meanwhile, the oxygen concentration in the first measurement chamber 20, thus controlled, is set to a low oxygen concentration, for example, an oxygen concentration of the order of 1000 ppm, which precludes the possibility of decomposition of the NOx components in the gas under measurement in the first measurement chamber 20. Thus, the reference voltage VC0 governing this oxygen concentration is set to a value on the order of 100 mV to 200 mV. A voltage VIP1 across both terminals of the resistor R0, provided between the output of the differential amplifier AMP and the porous electrode 4b for detecting the first pump current IP1, is entered to the ECU 50 as a detection signal for the first pump current IP1.

The driving circuit 40 is provided not only with the above-mentioned controller 40a, but also with a constant current circuit 40b connected via switch SW2 to the porous electrode 6c of the Vs cell 6 for causing a constant current to flow between the porous electrodes 6b and 6c in an opposite direction to the flowing direction of the small current iCP and with a constant current circuit 40c connected via switch SW3 to the porous electrode 6c of the Vs cell 6 for causing a constant current to flow between the porous electrodes 6b and 6c in the same direction as the flowing direction of the small current iCP.

These constant current circuits 40b, 40c operate for detecting the internal resistance RVS of the Vs cell 6. The voltage Vs of the porous electrode 6c is entered to the ECU 50 for enabling the internal resistance RVS of the Vs cell 6 to be detected by the ECU 50 by the supply of this constant current. The constant currents caused to flow by the constant current circuits 40b, 40c are of the same magnitude, although the current flowing directions are opposite to each other. This current value is larger than the small current iCP supplied via the resistor R2 to the Vs cell 6.

The switches SW1 to SW3, connected between the controller 40a, constant current circuits 40b and 40c, on the one hand, and the porous electrode 6c of the Vs cell, on the other hand, are turned on and off by a control signal from the ECU 50 for measuring the oxygen concentration and the NOx concentration. During normal operation, only the switch SW1 is turned on to operate the controller 40a. The switch SW1 is turned off only for detecting the internal resistance RVS of the Vs cell 6, while the switches SW2, SW3 are controlled to be turned on sequentially (alternately).

On the other hand, a constant voltage VP2 is impressed across the porous electrodes 8b, 8c of the second pump cell 8 of the NOx sensor 2 via a resistor R3 as constant voltage impressing means of the detection circuit 42. The constant voltage VP2 is impressed in such a direction that the porous electrodes 8c and 8b assume positive and negative, respectively, so that, in the second pump cell 8, the current will flow from the porous electrode 8c towards the porous electrode 8b for pumping oxygen in the second measurement chamber 26 to outside. Moreover, the constant voltage VP2 is set to a voltage capable of decomposing NOx components in the gas under measurement in the second measurement chamber flowing from the first measurement chamber 20 via diffusion rate regulating layers 6d, 22d for pumping out its oxygen component, such as, for example, 450mV.

The resistor R3 operates for converting the second pump current IP2 flowing in the second pump cell 8 on impression of the constant voltage VP2 into a voltage VIP2 which is entered as a detection signal for the first pump current IP2 to the ECU 50.

In the above-described oxygen concentration and nitrogen oxide concentration measurement device of the present embodiment, if the switch SW1 in the driving circuit 40 is turned on, while the switches SW2 and

of the first pump current IP1 and the second pump current IP2 when the device is actuated using a test gas not containing NOx as the gas being measured, the first pump current IP1 varies with a constant gradient in keeping with the oxygen concentration in the gas under measurement, while the second pump current IP2 varies also under the influence of the oxygen concentration in the gas under measurement.

Thus, in the present embodiment, in order for the second pump current IP2 to correspond only to the NOx concentration in the gas being measured, the value of the second pump current IP2 corresponding to the oxygen concentration obtained on measuring the gas under measurement free of NOx as described above is previously stored in a recording medium, such as ROM, as an offset value for correcting the second pump curent IP2, the oxygen concentration in the gas under measurement is detected from the first pump current IP1 and the offset value corresponding to this oxygen concentration is read out from the previously stored offset value data for setting as the above-mentioned reference correction amount.

For calculating this reference correction amount, a map having stored therein an offset value associated with the first pump current IP1 (reference correction amount) is used, and this map is retrieved using the first pump current IP1 as a parameter, for directly finding a reference correction amount from the first pump current IP1.

When the reference correction amount has been calculated in this manner, the processing proceeds to step S140 for reading in the internal resistance RVS of the Vs cell 6 obtained by the internal resistance detection processing as later explained. At the next step S150, the temperature correction amount for the second pump current IP2 is calculated based on the read value of the internal resistance RVS.

That is, in the present embodiment, the current supplied to the heaters 12, 14 is controlled so that the detected value of the internal resistance RVS of the Vs cell 6 will assume a pre-set value, in other words, so that the temperature of the NOx sensor 2 will assume a pre-set target temperature. However, if the temperature of the gas under measurement is changed abruptly, the temperature control cannot follow up the temperature changes in the gas under measurement, such that the temperature of the NOx sensor 2 may be occasionally changed based on changes in the temperature of the measured gas.

Fig.7 shows an example of measured results of temperature changes in the NOx sensor 2 when the NOx sensor 2 is mounted in an exhaust gas pipe of an internal combustion engine and the measurement device of the present embodiment is in operation for measuring the NOx concentration in the exhaust gas of the internal combustion engine. As may be seen from Fig.7, if, in the measurement device of the present embodiment, the exhaust gas temperature is transiently decreased with an increased amount of air intaken upon acceleration of the internal combustion engine, or if the exhaust gas temperature is transiently raised with a decreased amount of air taken upon deceleration thereof, both the first pump current IP1 and the second pump current IP2 are changed under the influence of such temperature changes despite temperature controls as later explained. In particular, it takes time as long as about one minute until the second pump current IP2 resumes its stable state. The reason is that, if the second pump current IP2 is affected by the exhaust gas temperature such that the oxygen concentration in the first measurement chamber 20 is deviated from the target concentration, it takes time until the oxygen concentration is reset to its target temperature.

Thus, in the present embodiment, the temperature of the Vs cell 6 is obtained from the internal resistance RVS of the Vs cell 6 and, using a map for calculating the amount of temperature correction shown for example in Fig.8, for enabling correct measurement of the NOx concentration from the second pump current IP2 even if the temperature of the measured gas is changed acutely.

The map shown in Fig.8 is designed for finding the amount of temperature correction from the device temperature of the Vs cell 6. However, if a map is prepared beforehand for calculating the amount of temperature correction having the internal resistance RVS of the Vs cell 6 as a parameter, the amount of temperature correction can be obtained directly from the internal resistance RVS without the necessity of re-calculating (or recovering) the internal resistance RVS into temperature. It is also possible to pre-set a map having an offset between the device temperature and the target temperature (850°C in Fig.8) in order to find the amount of temperature correction from the deviation from the target value of the device temperature. Alternatively, it is possible to previously set a map having an offset between the internal resistance RVS and a target resistance value associated with a target temperature as a parameter in order to find the amount of temperature correction from the offset (deviation) of the value of the internal resitance RVS from the target resistance value.

If the amount of temperature correction is found at step S150, proceeds transfers to step S160 where the amount of reference correction and the amount of temperature correction are summed to the second pump current IP2 detected at step S110 for correcting the second pump current IP2. At the next step S170, the as-corrected second pump current IP2 is outputted to an external device, such as an engine controlling device, as the results of measurement of the NOx concentration.

Next, the amount of temperature correction for the first pump current IP1 is calculated based on the internal resistance RVS read at step S140. At the next step S190, the first pump current IP1 detected at S120 is corrected, using the calculated amount of temperature cor-

current supply circuit 44 is constituted by a switching circuit capable of high-speed switching between the current supply and no current supply, it suffices to control a duty ratio of a driving pulse signal responsible for switching between the current supply and no current supply, whereas, if the heater current supply circuit 44 is constituted by a voltage control circuit capable of controlling an output voltage to the heaters 12, 14, it suffices if the voltage is increased or decreased based on the heater control signal from the ECU 50.

If the heater control signal is outputted in this manner, the processing proceeds to step S320 for judging whether or not a pre-set time T4, such as 500 μsec, has elapsed after start of the detection processing, to wait until lapse of the pre-set time T4. If the pre-set time T4 has elapsed, the detection processing is started at S330. The switch SW1, which has been off for the pre-set time T4, is turned on to terminate the detection processing for re-starting the operation of measuring the oxygen concentration and the NOx concentration.

In the above-described processing for detecting the internal resistance, the switch SW1 in the driving circuit 40 is turned off when the processing is started at time point t1 for stopping the supply of the small current iCP to the Vs cell 6 and the pump current control, whereupon the switch SW2 is turned on to cause the constant current to flow through the Vs cell 6 in a direction opposite to the flowing direction of the small current iCP. When the pre-set time T1 has elapsed at time point t2 since that time, the voltage Vs on the side of the porous electrode 6 at this time is set as a resistor detection voltage VS2 and the internal resistance RVS of the Vs cell 6 is detected from the offset ΔVs between the resistance detection voltage VS2 and the voltage Vs on the side of the porous electrode 6c at the time of starting the detection processing (i.e., basic detection voltage VS1), for the reason which will be now explained.

First, if the constant current for detecting the internal resistance is caused to flow through the Vs cell 6, the voltage Vs on the porous electrode 6c of the Vs cell 6 is varied not only by the internal resistance RVS of the Vs cell 6 but also by an electro-motive force generated responsive to a ratio between oxygen concentration values at both the electrodes 6b and 6c. Thus, in the present embodiment, in order for the voltage Vs on the porous electrode 6c for internal resistance detection to be less susceptible to the influence of the electromotive force, a current larger than the small current iCP is caused to flow for increasing a voltage drop caused by the internal resistance RVS of the Vs cell 6.

On the other hand, since the oxygen concentration values on the electrodes 6b, 6c of the Vs cell 6 are substantially constant by pump current control and by supply of the small current iCP, respectively, the electromotive force of the Vs cell 6 also becomes substantially constant. Thus, if the constant current is caused to flow across the Vs cell 6 thereupon detecting the voltage Vs on the porous electrode 6c, that is VS2, the internal resistance RVS of the Vs cell 6 can be determined substantially correctly from this voltage value.

However, more strictly, the oxygen concentration in the first measurement chamber 20 is controlled by feedback control of the pump current and hence is fluctuated due to, for example, response delay of the control system, such that it cannot be fixed at a constant concentration value. On the other hand, the oxygen concentration in the first measurement chamber 20 is also varied depending on the temperature of the NOx sensor 2. Thus, if the internal resistance RVS is determined from the voltage Vs detected by causing the RVS detecting constant current to flow through the Vs cell 6, there might result an error, even if small, in the internal resistance RVS.

Thus, in the instant embodiment, the amount of change in the voltage Vs on the porous electrode 6c (offset ΔVs) until a pre-set time, such as 60 μsec, elapses after the time the constant current for detecting the internal resistance RVS is caused to flow through the Vs cell 6 is detected, and the internal resistance RVS is determined from this offset ΔVs. Based on this, the internal resistance RVS of the Vs cell 6 and hence the device temperature can be accurately determined even if the oxygen concentration in the first measurement chamber 20 is deviated from the target concentration.

For calculating the internal resistance RVS, the following may be employed. A map having previously stored therein the internal resistance RVS versus the offset ΔVs is provided, and the internal resistance RVS is calculated using this map.

Next, in the processing for detecting the internal resistance of the instant embodiment, if a resistance detection voltage VS2 is set at a time point t2 upon lapse of a pre-set time interval T1 (at time point t2) after start, the switches SW2 and SW3 are turned off and on, respectively, when another pre-set time, such as 40 μsec, has elapsed further at time point t3 at which the elapsed time after the start of the detection processing has reached T2. This causes the constant current to flow through the Vs cell 6 in the same direction as the small current iCP. If a further pre-set time, such as 100 μsec, has elapsed further at time point t4 at which the elasped time after the start of the detection processing has reached T3, the switch SW3 is turned off.

The result is as follows, in the instant embodiment. Since oxygen pumped from the closed space on the porous electrode 6c of the Vs cell for detecting the internal resistance RVS can be returned quickly. Besides the current is caused to flow in the opposite direction to the flowing direction of iCP for reverting the internal polarized state of the Vs cell 6 to an original state, so that the closed space towards the porous electrode 6c can operate quickly as the internal reference oxygen source, as well as the Vs cell 6 can be operated quickly as the oxygen concentration measurement cell. Thus a length of

be a pre-set target temperature.

3. The method as defined in claim 1 or 2, wherein the measured results of the oxygen concentration and the nitrogen oxide concentration are corrected depending on the deviation from the target value of the temperature of the oxygen concentration measurement cell for compensating the measured results for temperature.

4. A device for measuring the oxygen concentration and the nitrogen oxide concentration in a gas under measurement comprising:

an NOx sensor (2) having a first measurement chamber (20), a second measurement chamber (26) and a heater (12, 14), said first measurement chamber (20) having a first oxygen pumping cell (4) and an oxygen concentration measuring cell (6) and communicating with the side of the gas under measurement via a first diffusion rate regulating layer (4d), said first oxygen pumping cell (4) having an oxygen ion conductive solid electrolyte layer (4a) sandwiched between porous electrodes (4b1, 4c1), said second measurement chamber (26) having a second oxygen pumping cell (8) having an oxygen ion conductive solid electrolyte layer (6a) sandwiched between porous electrodes (6b1, 6c1), and communicating with the first measurement chamber (20) via a second diffusion rate regulating layer (6d, 22d), and said heater (12, 14) being adapted for heating the cells to a pre-set activation temperature;

pump current control means (40a) for causing the current to flow in said first oxygen pumping cell (4) so that an output voltage of the oxygen concentration measurement cell will be of a pre-set value for controlling the oxygen concentration in the first measurement chamber (20) to a constant value;

constant voltage application means (40b) for applying a constant voltage across said second oxygen pumping cell (8) in a direction of pumping out oxygen out of the second measurement chamber (26);

nitrogen oxide concentration measurement means for measuring the concentration of nitrogen oxide in the gas under measurement based on the value of the current (IP2) flowing in the second oxygen pumping cell (8); and

oxygen concentration measurement means for measuring the oxygen concentration in the gas under measurement based on the value of the current (IP1) flowing in the first oxygen pumping cell (4).

5. The device as defined in claim 4 further comprising:

temperature detection means for detecting the temperature of the oxygen concentration measurement cell; and/or

heater current supplying controlling means (44) for controlling the current supplied to said heater (12, 14) so that the temperature of said oxygen concentration measurement cell as detected by said temperature detection means will be a pre-set target temperature.

6. The device as defined in claim 5; further comprising:

correction means for temperature-compensating results of measurement of the oxygen concentration and the nitrogen oxide concentration by correcting said results of measurement responsive to deviation from said target temperature of the temperature of the oxygen concentration measurement cell as detected by said temperature detection means.

7. The device as defined in claim 5 or 6 wherein said temperature detection means detects the temperature of the oxygen concentration measurement cell (6) by detecting the internal resistance of said measurement cell and wherein said heater current supply controlling means controls the current supplied to said heater (12, 14) so that the detected internal resistance of the oxygen concentration measurement cell will be of a pre-set value corresponding to the target temperature.

8. The device as defined in any one of claims 4 to 7 wherein, in said NOx sensor (2), the porous electrode on the side of the oxygen concentration measurement cell (6) opposite to the first measurement chamber (20) is closed, and part of oxygen in the resulting closed space can be leaked out via a leakage resistance; and/or wherein

said pump current control means causes a small amount of current to flow in said oxygen concentration measurement cell (6) in a direction of pumping out oxygen in said first measurement space into said closed space to control the amount of current flowing in said first oxygen pumping cell (4) so that, as said closed space is caused to function as an internal oxygen reference source, an electromotive force generated across said oxygen concentration measurement cell will be of a constant

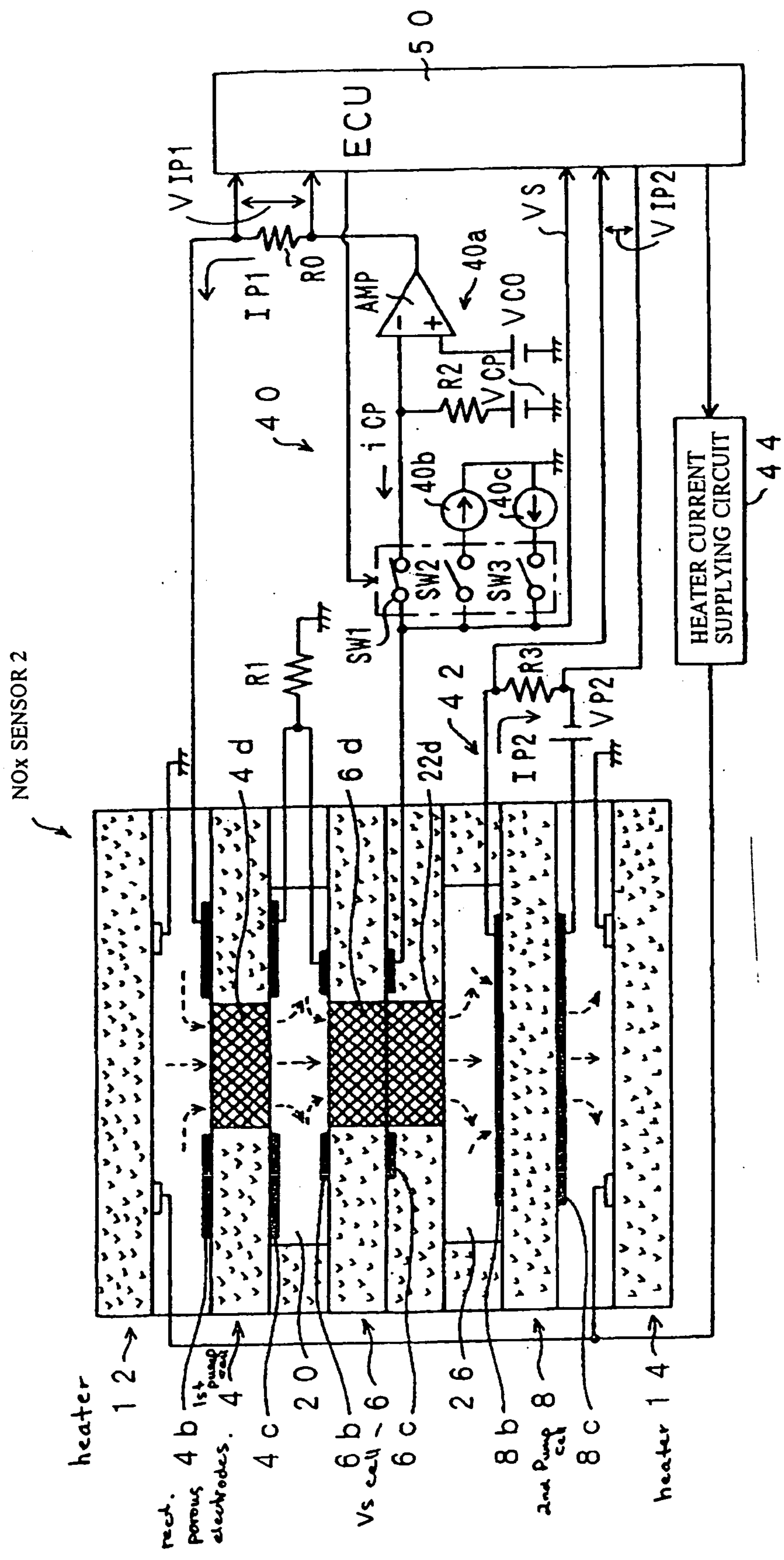

ECU
50
VIP1
IP1
R0
AMP
40a
VC0
R2
VCP
iCP
40
40b
40c
SW1
SW2
SW3
R1
42
R3
VP2
IP2
VS
VIP2
HEATER CURRENT SUPPLYING CIRCUIT
44
NOx SENSOR 2
4d
6d
22d
heater
12
4b
1st pump cell
4
4c
20
6b
6
6c
26
8b
8
8c
14
rect. porous electrodes.
Vs cell
2nd Pump cell
heater

FIG. 1

FIG. 3

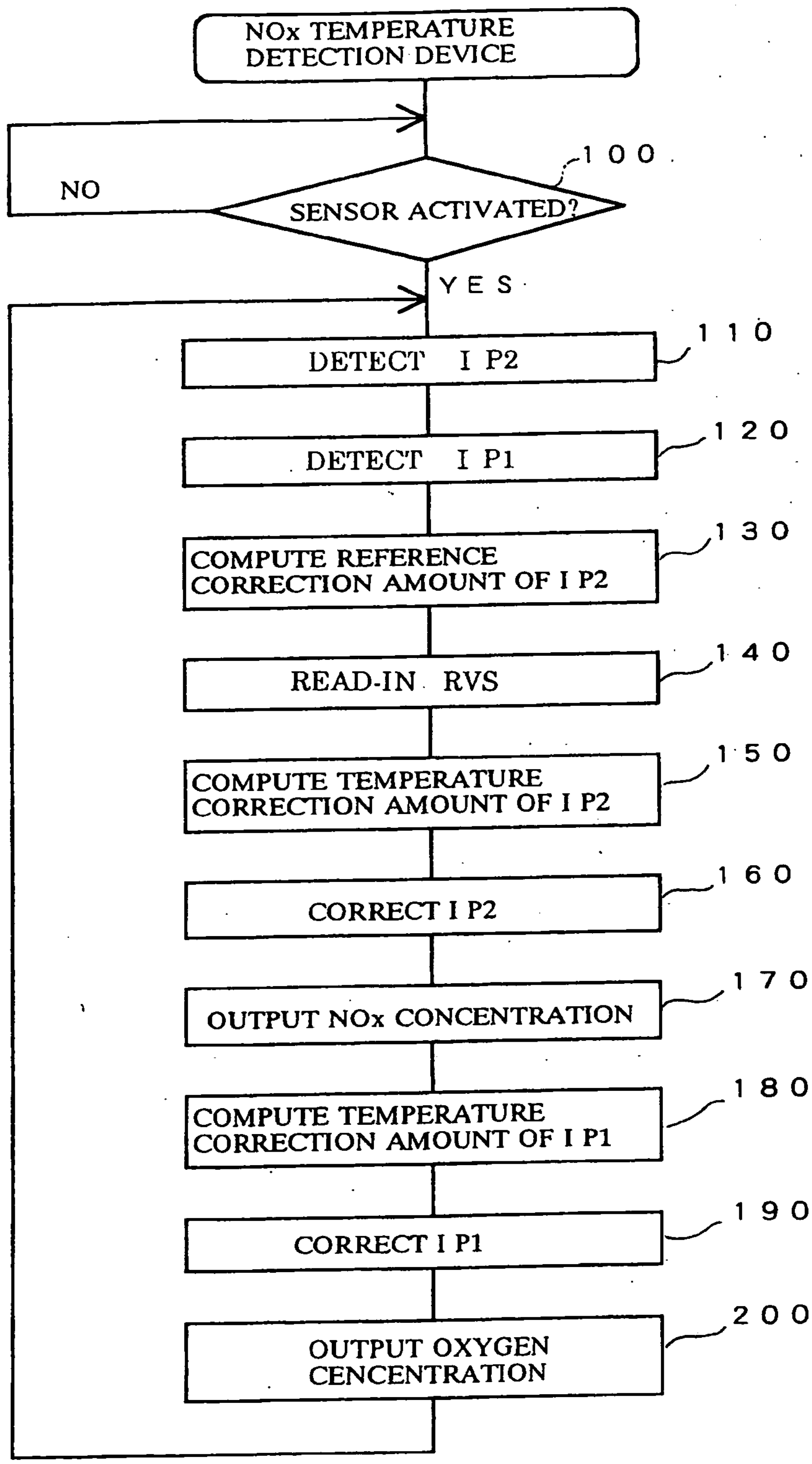

NOx TEMPERATURE DETECTION DEVICE
100
SENSOR ACTIVATED?
NO
YES
110
DETECT I P2
120
DETECT I P1
130
COMPUTE REFERENCE CORRECTION AMOUNT OF I P2
140
READ-IN RVS
150
COMPUTE TEMPERATURE CORRECTION AMOUNT OF I P2
160
CORRECT I P2
170
OUTPUT NOx CONCENTRATION
180
COMPUTE TEMPERATURE CORRECTION AMOUNT OF I P1
190
CORRECT I P1
200
OUTPUT OXYGEN CENCENTRATION

FIG. 5

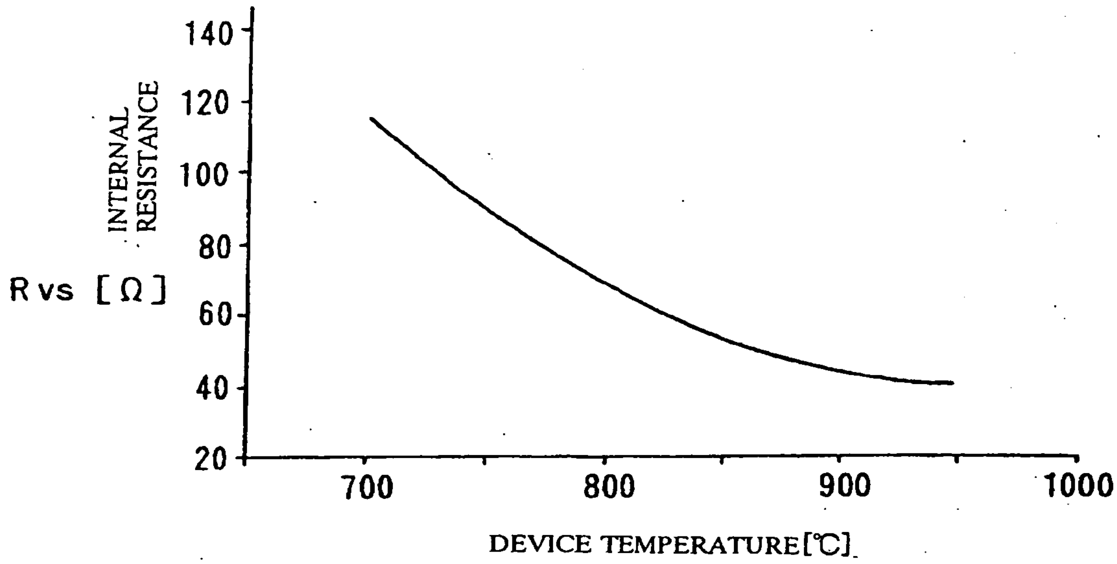

140
120
100
80
60
40
20
INTERNAL RESISTANCE
Rvs [Ω]
700
800
900
1000
DEVICE TEMPERATURE[℃]

FIG. 6

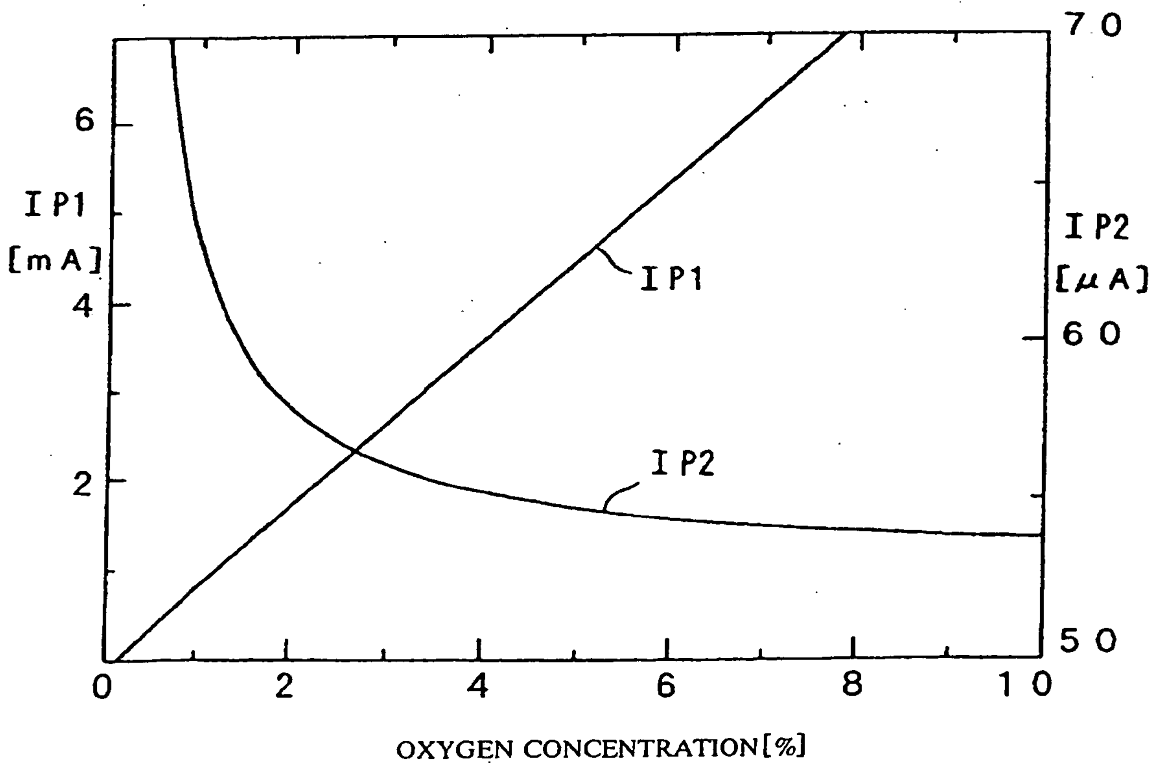

6
4
2
0
IP1
[mA]
IP1
IP2
70
60
50
IP2
[μA]
2
4
6
8
10
OXYGEN CONCENTRATION[%]

FIG. 9

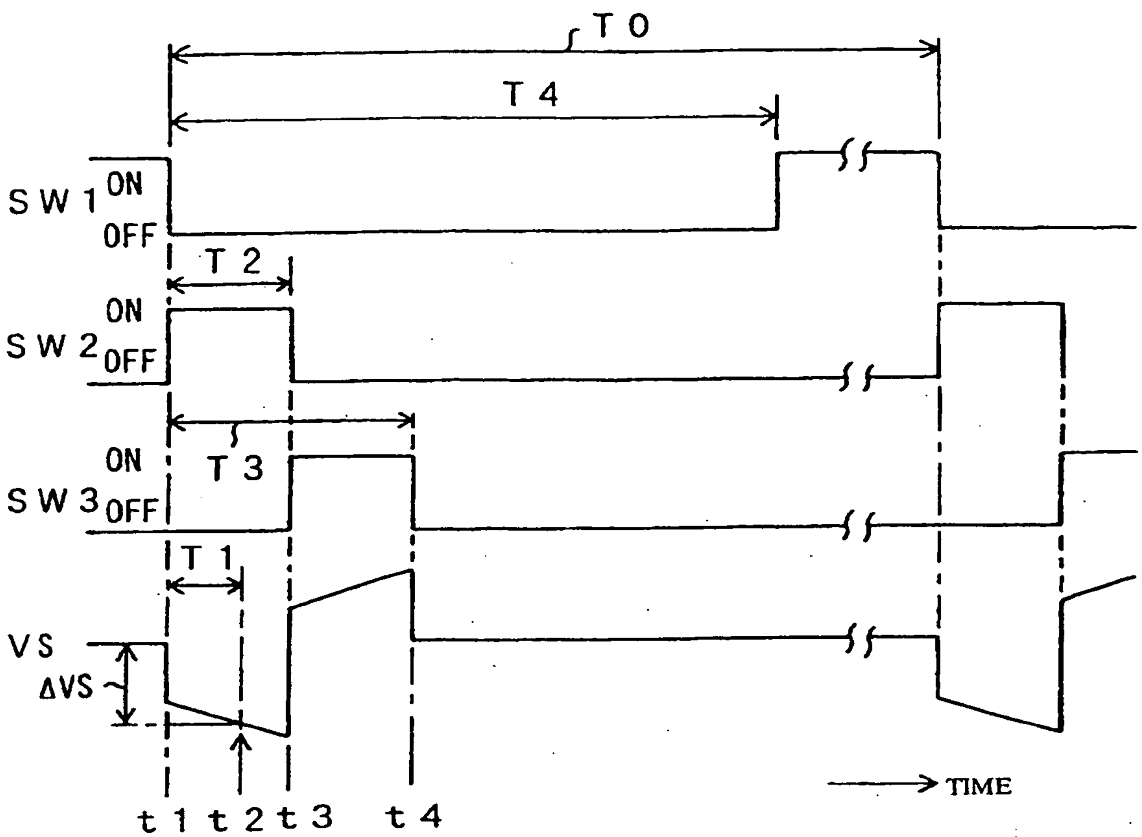
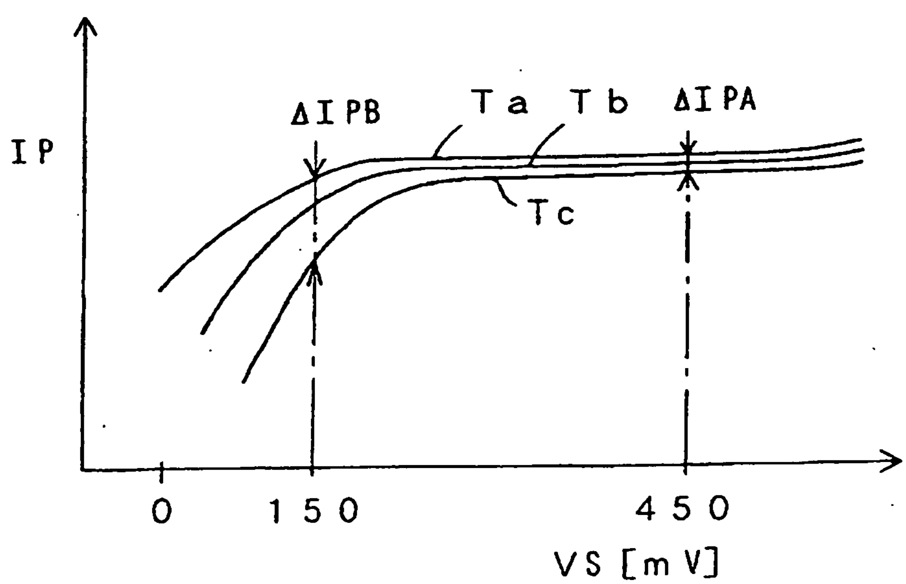

T 0
T 4
SW 1
ON
OFF
T 2
SW 2
ON
OFF
T 3
SW 3
ON
OFF
T 1
VS
ΔVS
TIME
t 1 t 2 t 3 t 4

FIG. 10


IP
ΔIPB
Ta
Tb
ΔIPA
Tc
0
150
450
VS [mV]

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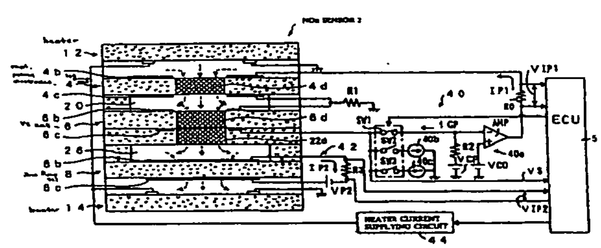
(54) **Method and apparatus for measuring oxygen concentration and nitrogen oxide concentration**

(57) Using a sole Nox sensor Nox concentration and oxygen concentration are measured accurately. A measurement device for measuring NOx concentration and oxygen concentration comprises an NOx sensor (2) having a first measurement chamber (20) communicating via a diffusion rate regulating layer (4d) with the gas under measurement and a second measurement chamber (26) communicating with the first measurement chamber (20) via diffusion rate regulating layers (6d, 22d). A first pump cell (4) and an oxygen concentration measurement Vs cell (6) are formed on the first measurement chamber (20), while a second pump cell (8) is formed on the second measurement chamber (26). Inside of the first measurement chamber (20) is controlled to a constant low oxygen concentration by controlling the first pump current (IP1) so that output of Vs cell (6) will equal a reference voltage VC0. By applying a constant voltage across the second pump cell (8) NOx in the second measurement chamber (26) is decomposed to pump out oxygen. Thus NOx concentration and oxygen concentration are measured from the second pump current (IP2) and from the first pump current (IP1), respectively. During measurement, sensor temperature is detected from the internal resistance of the Vs cell for controlling heater current supplied to heaters (12, 14) to maintain a constant sensor temperature.

FIG. 1



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EUROPEAN SEARCH REPORT

Application Number
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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US 5 524 472 A (HOETZEL GERHARD) 11 June 1996 * figure 1 * ---	1-15	
A	US 5 340 462 A (SUZUKI HIROYOSHI) 23 August 1994 * claim 1; figure 5 * -----	1-15	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	10 August 1998	Mason, W

CATEGORY OF CITED DOCUMENTS

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